



New particles at Belle

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Contents

■ Bottomonium-like exotics

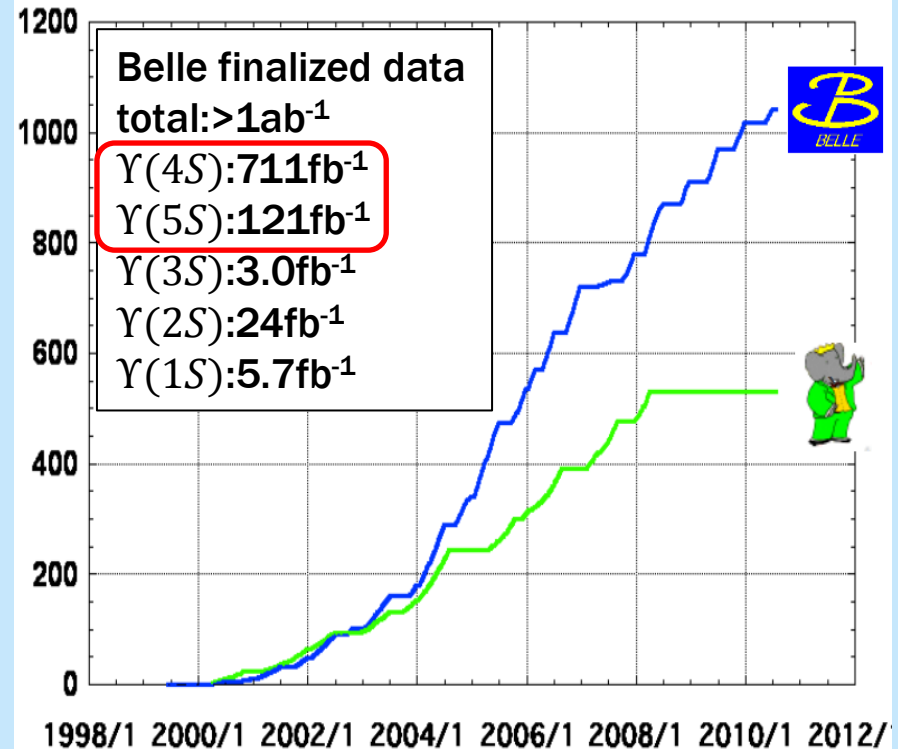
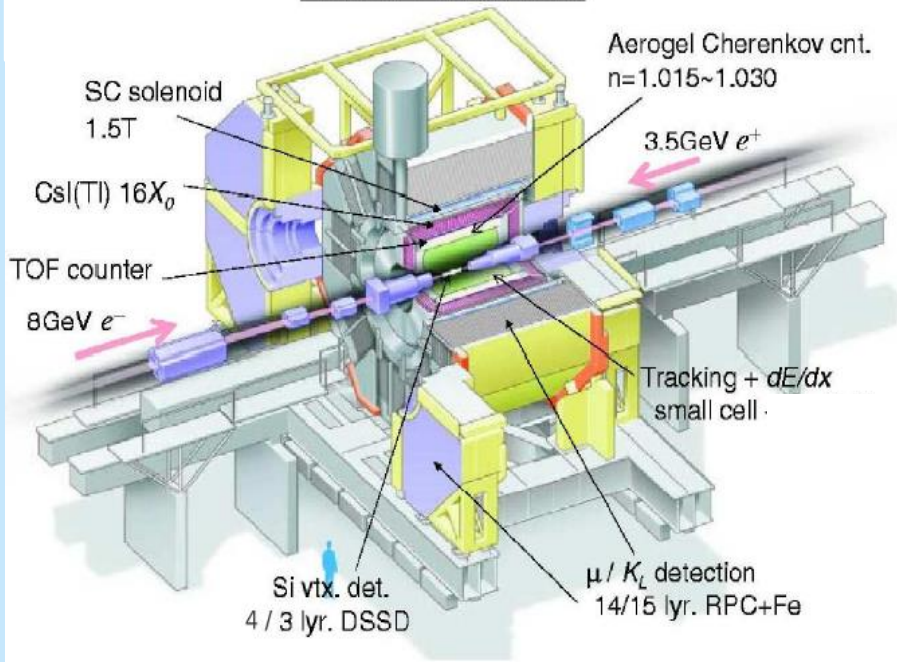
- Evidence for neutral partner $Z_b^0 \rightarrow \Upsilon(nS)\pi^0$ [arXiv:1207.4345](#)
- New decay mode of charged bottomonium-like $Z_b^+ \rightarrow (B^{(*)}\bar{B}^*)^+$ [arXiv:1209.6450](#)

■ Charmonium-like exotics

- Determination of J^P for $Z(4430)^+$
 - $Z(4430)^+ \rightarrow \psi'\pi^+$ in $B^0 \rightarrow \psi'\pi^+K^-$ [arXiv:1306.4894](#)
- Search for C-odd partner of $X(3872)$
 - $X(3872) \rightarrow J/\psi\eta$ in $B^\pm \rightarrow J/\psi\eta K^\pm$ **preliminary**
 - $X(3872) \rightarrow \chi_{c1}\gamma$ in $B^\pm \rightarrow \chi_{c1}\gamma K^\pm$ [arXiv:1304.3975](#)
 - Evidence for D-wave spin 2 state $\psi_2(1D)$ **To appear in PRL**

KEKB and Belle Detector

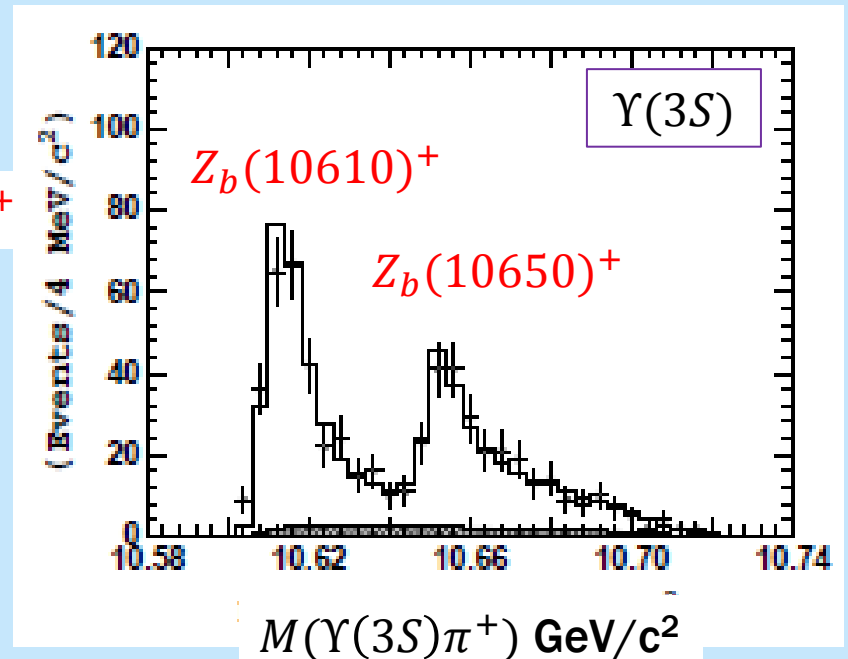
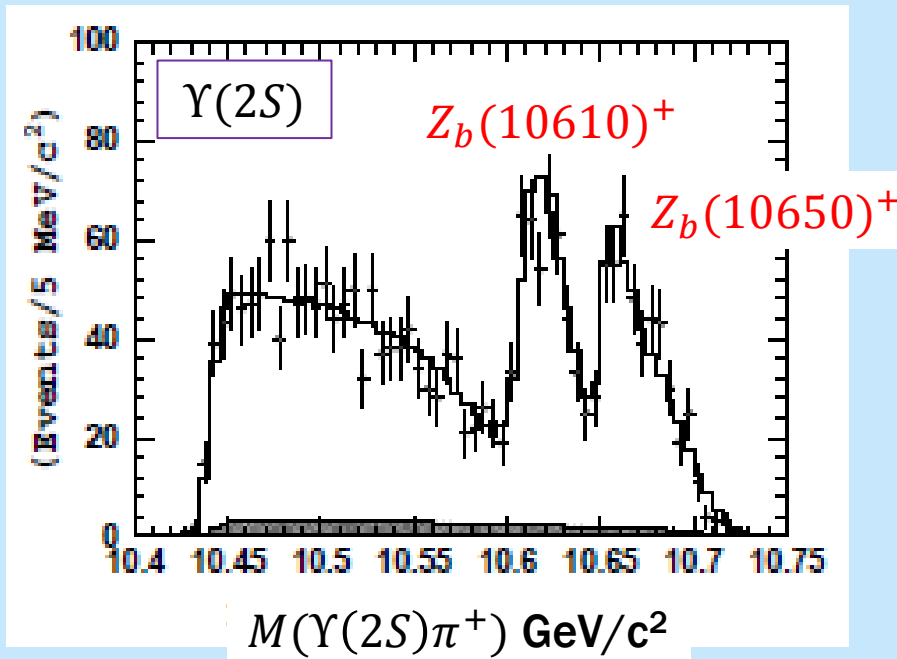
Belle Detector



Asymmetric energy e^+e^- collider
(electron 8 GeV and Positron 3.5 GeV for $\Upsilon(4S)$)

Bottomonium-like exotics

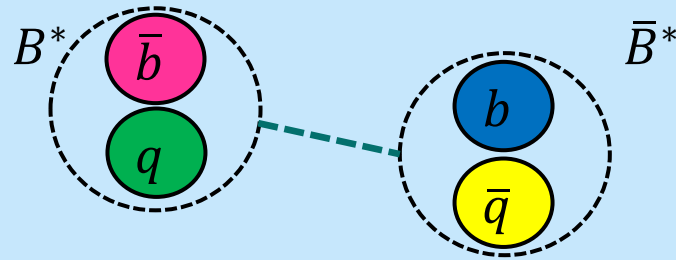
- $Z_b(10610)^+$ and $Z_b(10650)^+$ are discovered in $\Upsilon(nS)\pi^+$, $h_b(mP)\pi^+$ mass spectrum in $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^+\pi^-$ and $\Upsilon(5S) \rightarrow h_b(mP)\pi^+\pi^-$



Belle, PRL 108,122001

Bottomonium-like exotics 2

- One possible interpretation for $Z_b(10610)^+$ and $Z_b(10650)^+$ is $B^{(*)}\bar{B}^*$ molecular state



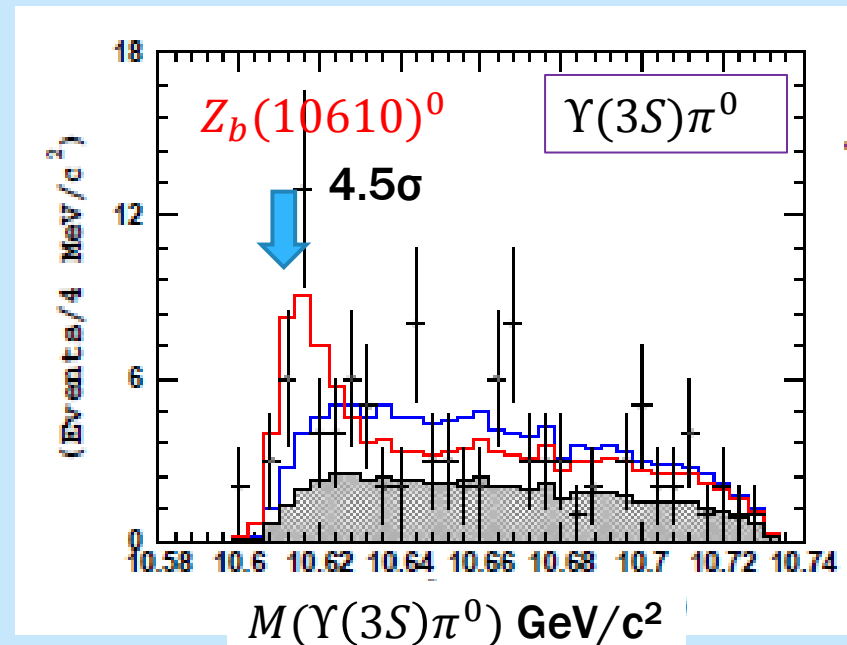
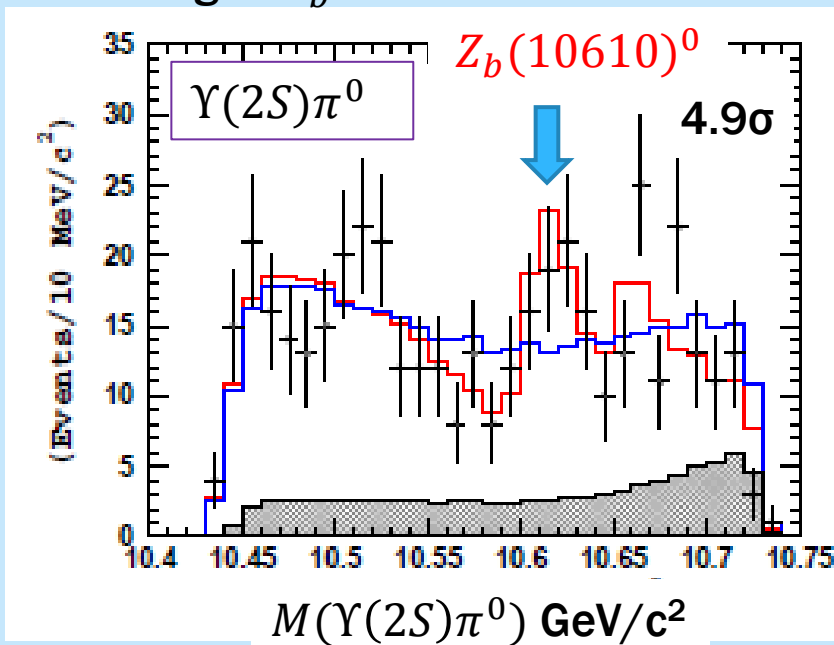
- Following items
 - Neutral $Z_b^0 \rightarrow \Upsilon(2,3S)\pi^0$ modes
 - Studying $Z_b^+ \rightarrow B^{(*)}\bar{B}^*$

Search for neutral Z_b in $\Upsilon(nS)\pi^0$ $n = 1, 2, 3$

■ $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^0\pi^0$ decay

In this fit mass and width are fixed from the charged Z_b result.

— fit result with Z_b
 — fit result without Z_b



Simultaneous fit gives 6.3σ for $Z_b(10610)^0$

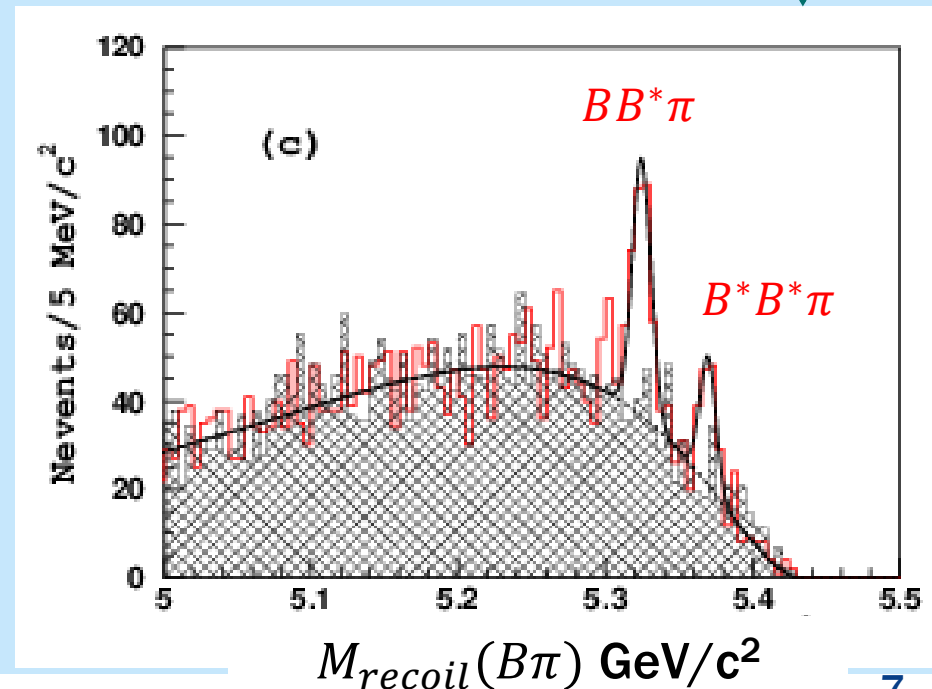
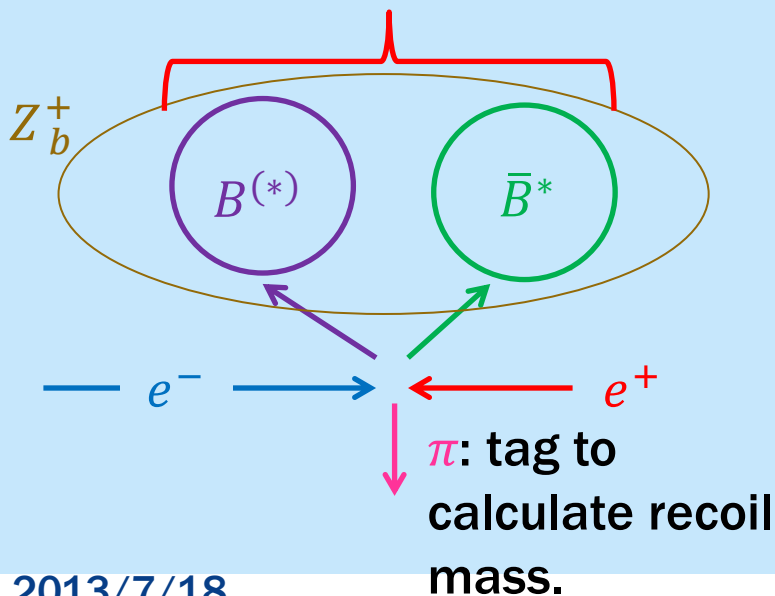
arXiv:1207.4345

$$\Upsilon(5S) \rightarrow Z_b^+ \pi^-, Z_b^+ \rightarrow (B^{(*)} \bar{B}^*)^+$$

Event selection

arXiv:1209.6450

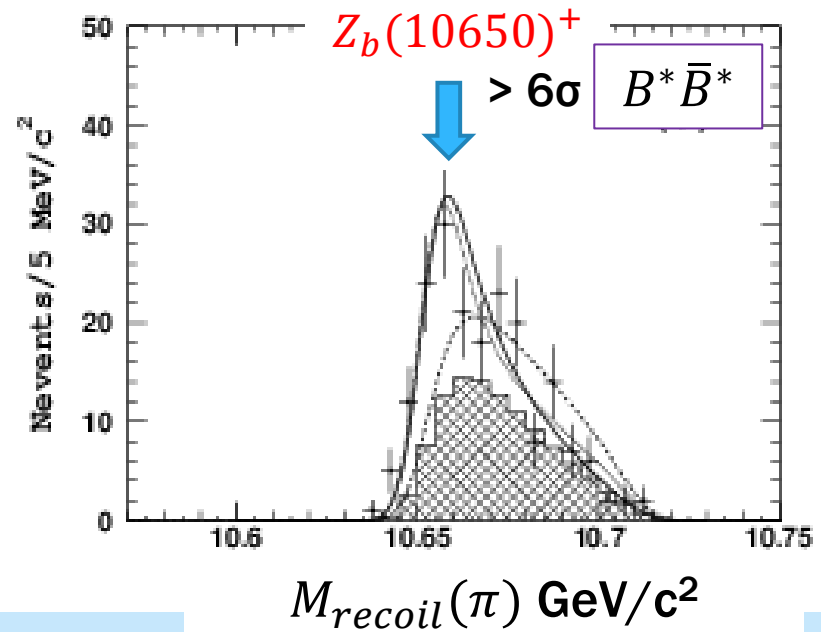
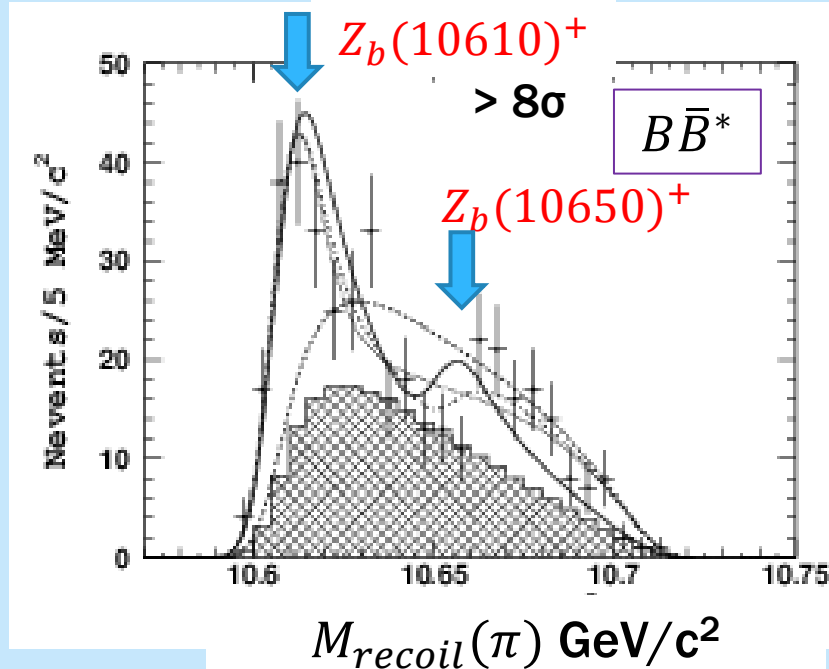
- Use $\Upsilon(5S)$ data sample
- One B meson is fully reconstructed (total 8 modes)
- Calculate $M_{recoil}(B\pi)$ to select $BB^*\pi$ and $B^*B^*\pi$ events
- Calculate $M_{recoil}(\pi)$ to see if there is a peak



$M_{recoil}(\pi)$ distribution in $\Upsilon(5S) \rightarrow B^{(*)} \bar{B}^* \pi$

Preliminary

arXiv:1209.6450



$Z_b(10610)^+$ in $B\bar{B}^*$ and $Z_b(10650)^+$ in $B\bar{B}^*/B^*\bar{B}^*$ are seen.
This observation supports the molecular picture.

Charmonium-like exotics

- Quantum numbers : key to test possible interpretation

- $Z(4430)^+$ J^P

- Angular distribution in $\bar{B}^0 \rightarrow \psi' \pi^+ K^-$

- Search for C-odd partner of $X(3872)$

In either tetraquark or molecule pictures, $X(3872)$ can have C-odd partner which may decay into $J/\psi\eta$ and $\chi_{c1}\gamma$

- $J/\psi\eta$ mass distribution $B \rightarrow J/\psi\eta K$

- $\chi_{c1}\gamma$ mass distribution $B \rightarrow \chi_{c1(c2)}\gamma K$

As for $Z_c(3895)^+ \rightarrow J/\psi\pi^+$, see M.Z.Wang's talk in the QCD session.

Quantum number of $Z(4430)^+$

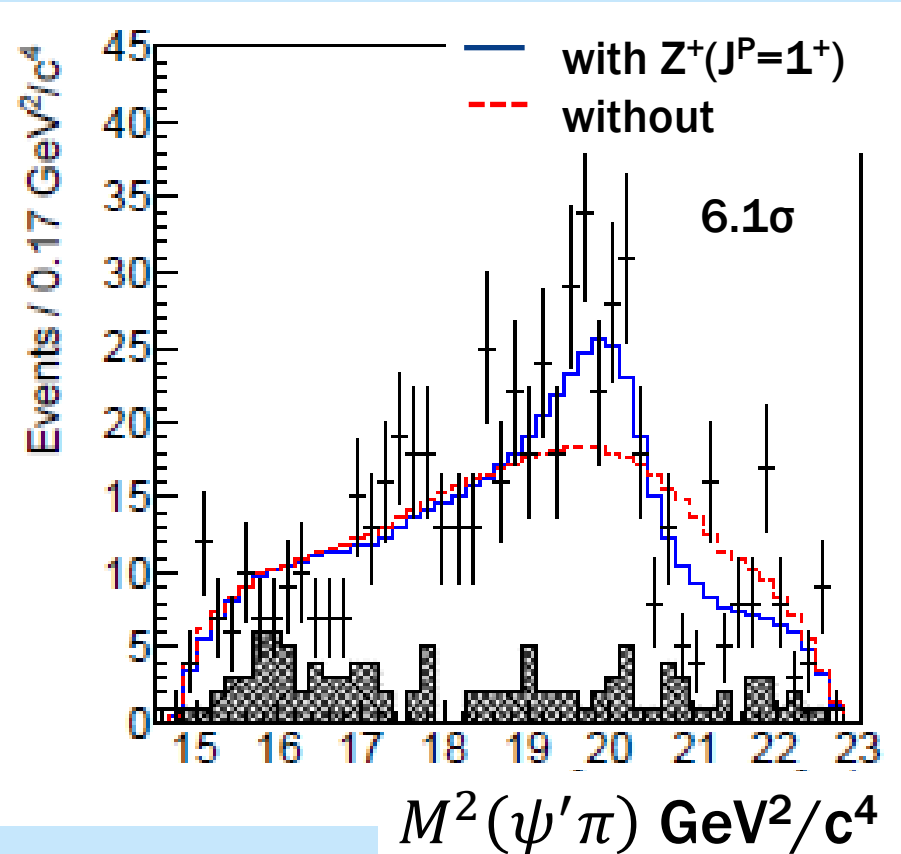
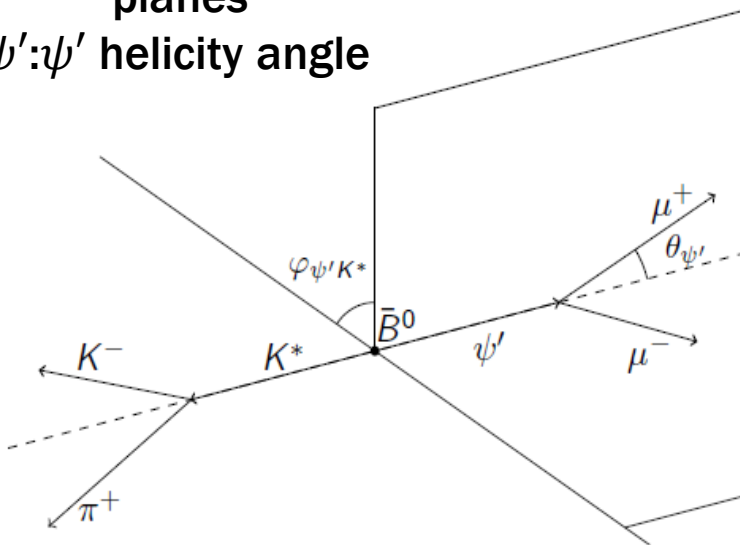
- $\bar{B}^0 \rightarrow \psi' \pi^+ K^-$ decay mode

arXiv:1306.4894

- Amplitude analysis in 4D space is performed
 $(M^2(K\pi), M^2(\psi'\pi), \phi\psi', \theta\psi')$

$\phi\psi'K^*$: angle between ψ' and K^* decay planes

$\theta\psi'$: ψ' helicity angle



Quantum number of $Z(4430)^+$ (2)

■ Summary of fit results

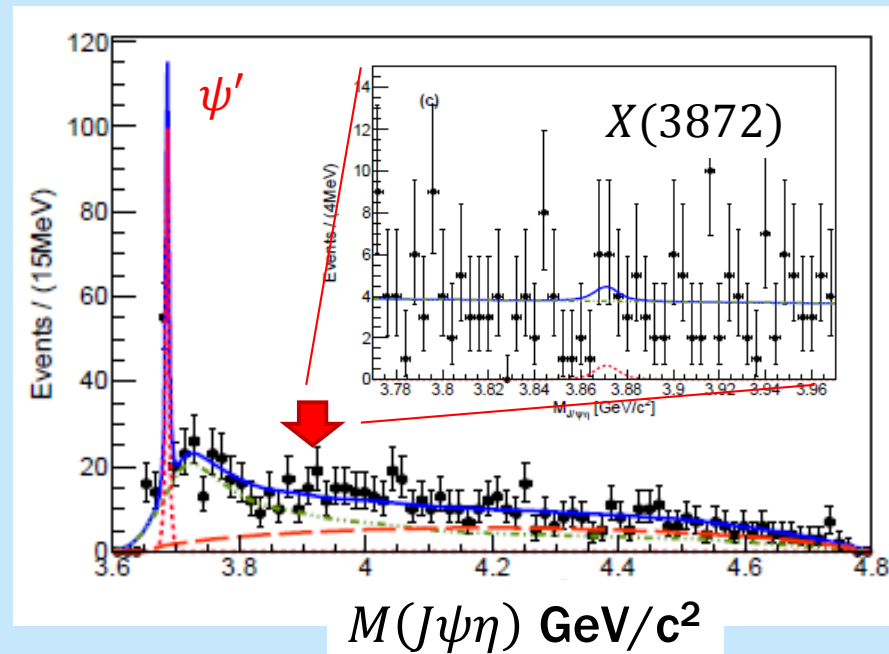
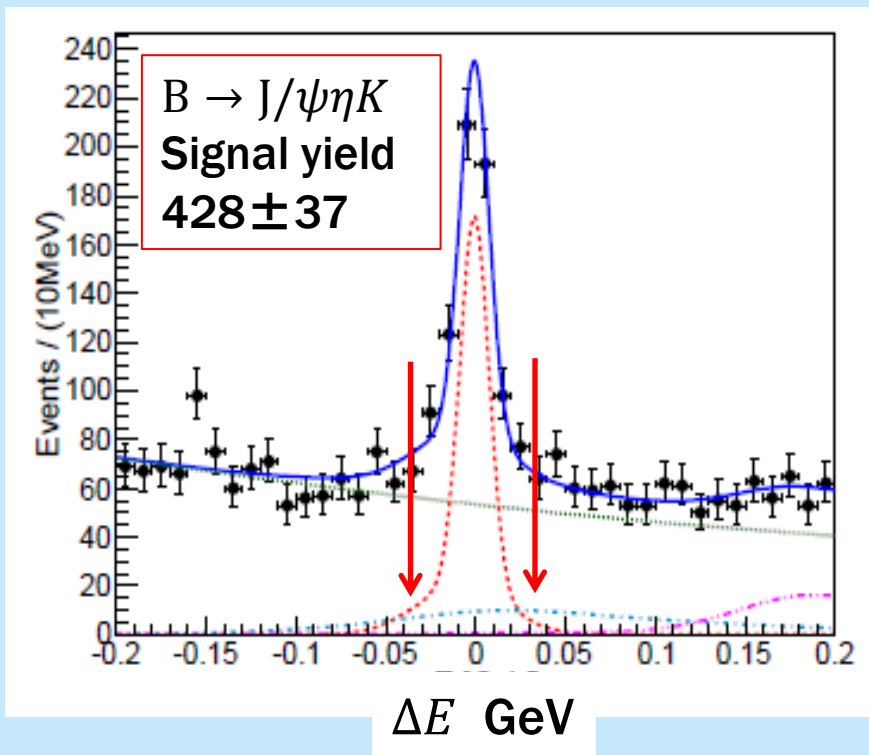
J^P	0^-	1^-	1^+	2^-	2^+
Mass, MeV/c^2	4470 ± 20	4482 ± 4	4500 ± 12	4545 ± 2	4367 ± 2
Width, MeV	139 ± 36	10.9 ± 0.3	126 ± 20	11.2 ± 0.6	9.1 ± 0.6
Significance	4.4σ	1.2σ	6.1σ	2.3σ	2.6σ

(With and without Z^+)

- The 1^+ hypothesis is preferred.
- Exclusion levels are calculated from toy MC
 - 0^- is not excluded.
 - 1^+ is favorable over 0^- by 2.9σ .
 - 1^- , 2^- and 2^+ are excluded at levels of 5.5σ , 4.3σ , and 5.4σ

Search for C-odd partner of $X(3872)$ in $B \rightarrow J/\psi\eta K$ decay

Preliminary



$$\text{Br}(B \rightarrow X(3872)K) \cdot \text{Br}(X(3872) \rightarrow J/\psi\eta) < 3.8 \times 10^{-6} \quad @ 90\% \text{ C.L.}$$

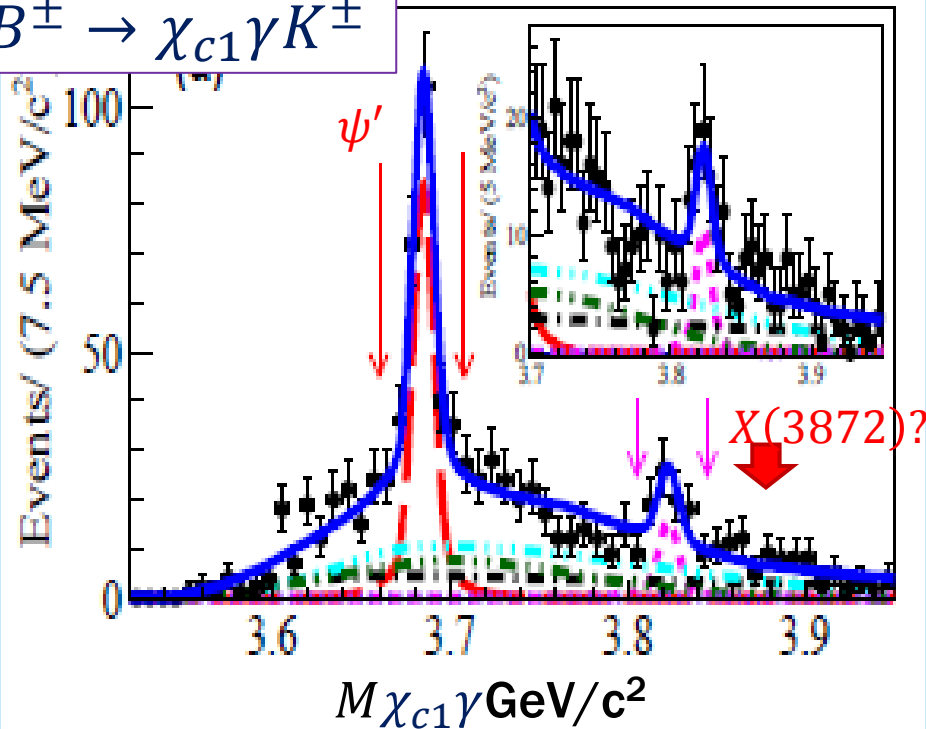
There is no evidence for C-odd partner of $X(3872)$ and other state.

$$\Delta E = E_{Bcand}^* - \frac{\sqrt{s}}{2}$$

Search for C-odd partner of $X(3872)$ in $B^\pm \rightarrow \chi_{c1}\gamma K^\pm$

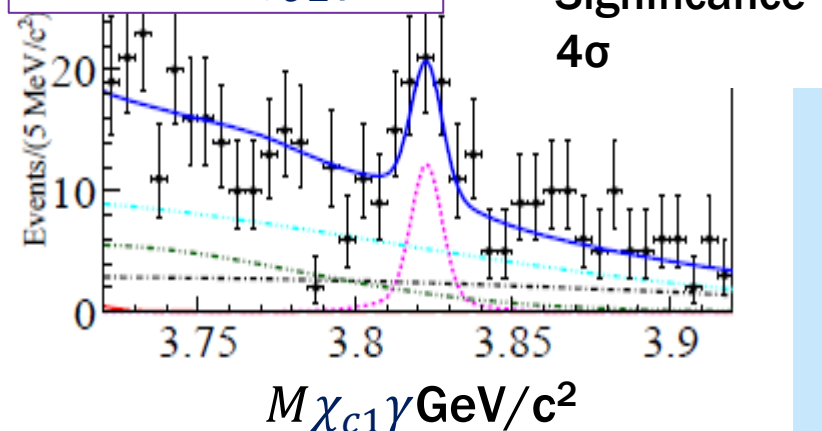
arXiv:1304.3975
To appear in PRL

$B^\pm \rightarrow \chi_{c1}\gamma K^\pm$



Simultaneous fit to $B^\pm \rightarrow \chi_{c1}\gamma K^\pm$ and
 $B^0 \rightarrow \chi_{c1}\gamma K_S$ modes

$B^{+,0} \rightarrow \chi_{c1}\gamma K$

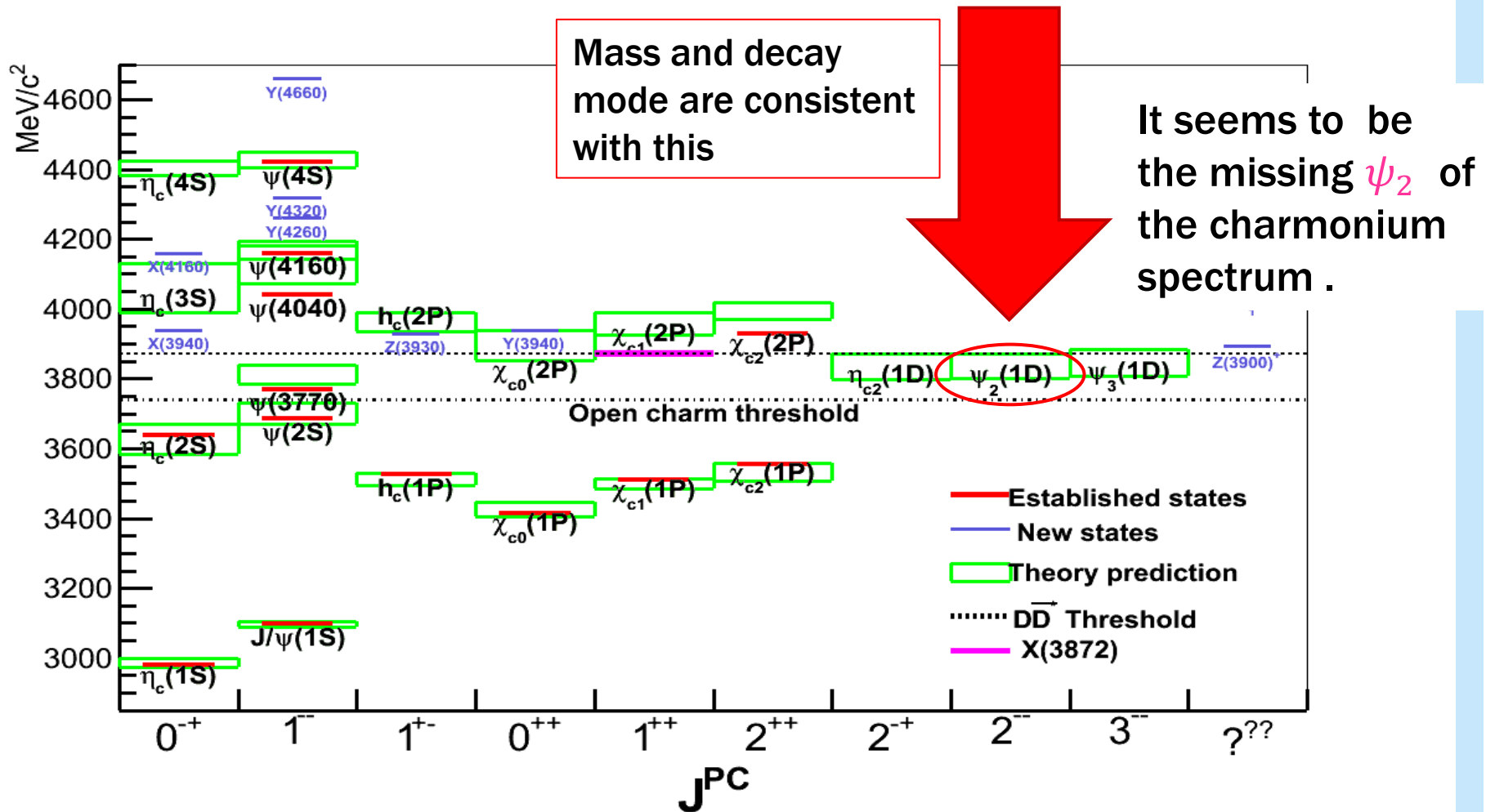


Again no evidence for C-odd partner of $X(3872)$.

But we found narrow peak at 3823 MeV.

Mass is $3823.1 \pm 1.8 \pm 0.7$ MeV

New member of charmonium



Summary

■ Bottomonium-like exotics

- Neutral $Z_b(10610)^0$ is observed in $\Upsilon(2,3S)\pi^0$ at 6.3σ
- We found $Z_b(10610)^+$ and $Z_b(10650)^+$ decay to $B^{(*)}\bar{B}^*$ at more than 8σ and 6σ , respectively.

■ Charmonium-like exotics

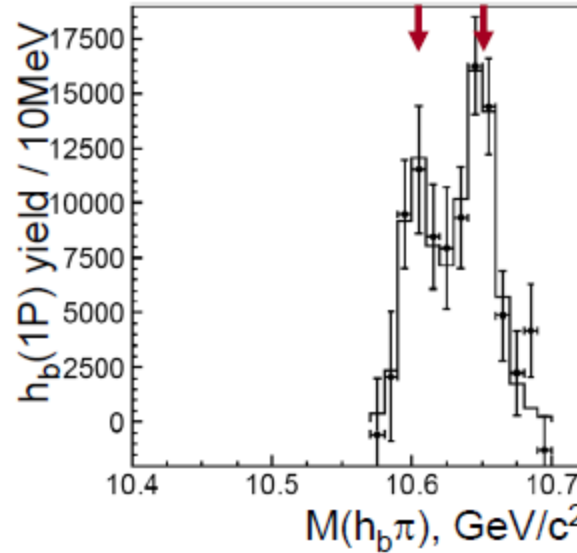
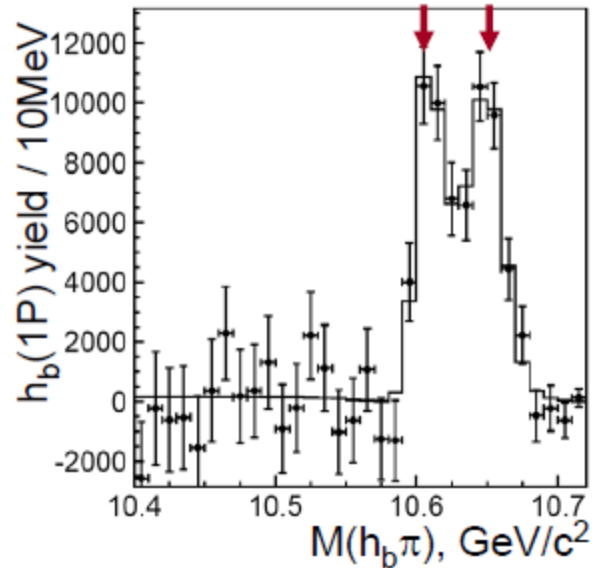
- As quantum number of $Z(4430)^+$, $J^P=1^+$ is preferred.
- There is no evidence of C-odd partner of $X(3872)$ in $J/\psi\eta$ and $\chi_{c1}\gamma$ states.
- Peak at 3823 MeV in $\chi_{c1}\gamma$ at 4σ , consistent with $\psi_2(1D)$.

Back up

Discovery of Z_b

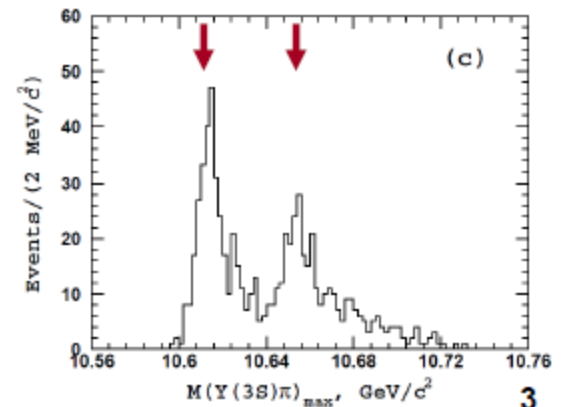
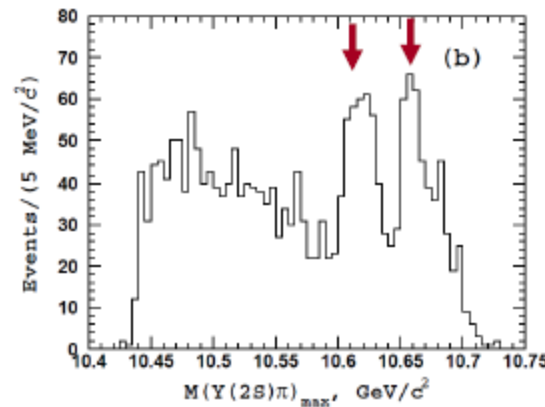
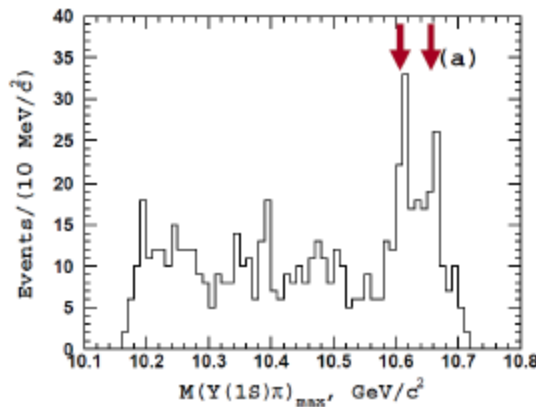


In analysis of $\Upsilon(5S) \rightarrow h_b(mP)\pi^+\pi^-$ and $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^+\pi^-$



fit $M_{\text{miss}}(\pi^+\pi^-)$
in $M(h_b\pi)$ bins

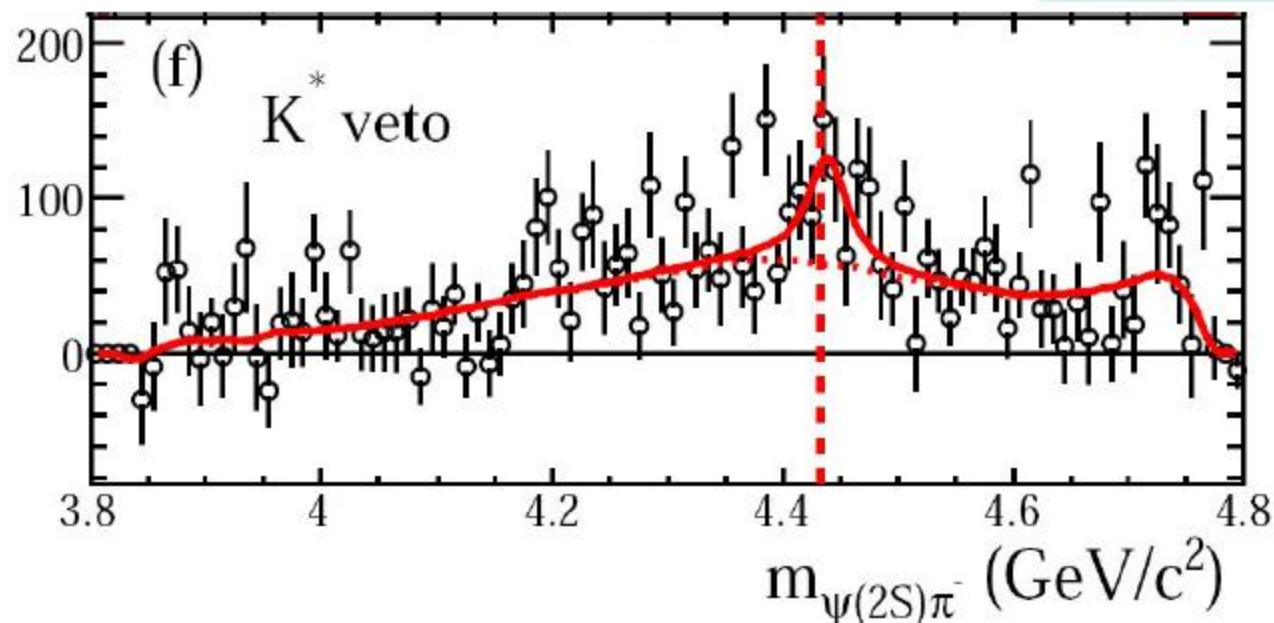
PRL 108, 122001
(2012)





BaBar doesn't see a significant $Z(4430)^+$

PRD79, 112001 (2009)



“For the fit ... equivalent to the Belle analysis...we obtain mass & width values that are consistent with theirs,... but only $\sim 1.9\sigma$ from zero; fixing mass and width increases this to only $\sim 3.1\sigma$.”

$$\text{BF}(B^0 \rightarrow Z^+ K) \times \text{BF}(Z^+ \rightarrow \psi(2S)\pi^+) < 3.1 \times 10^{-5}$$

$$\text{Belle PRL: } (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$$

9

Measurement of $Z(4430)^+$ quantum numbers

NEW

★ Amplitude analysis in 4D phase:

$(M^2_{K\pi}, M^2_{\psi' \pi}, \phi_{\psi' K^*}, \theta_{\psi'})$.

$\phi_{\psi' K^*}$: angle between Ψ' and K^* decay planes

$\theta_{\psi'}$: Ψ' helicity angle

TABLE I: Fit results: $Z^+ \rightarrow \psi' \pi^+$.

J^P	0^-	1^-	1^+	2^-	2^+
Mass, MeV	4470 ± 20	4482 ± 4	4500 ± 12	4545 ± 2	4367 ± 2
Width, MeV	139 ± 36	10.9 ± 0.3	126 ± 20	11.2 ± 0.6	9.1 ± 0.6
Significance	4.4σ	1.2σ	6.1σ	2.3σ	2.6σ

★ The 1^+ hypothesis is preferred

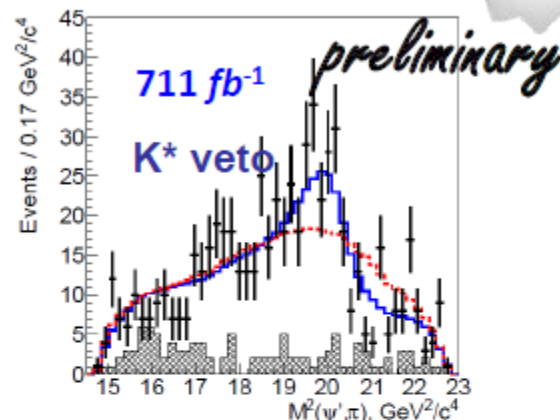
★ Exclusion levels are calculated from toy MC

★ 0^- is not excluded; significance of 1^+ over 0^- is 2.9σ . 1^- , 2^- and 2^+ are excluded at levels of 5.5σ , 4.3σ , and 5.4σ

★ We also calculated some Brs:

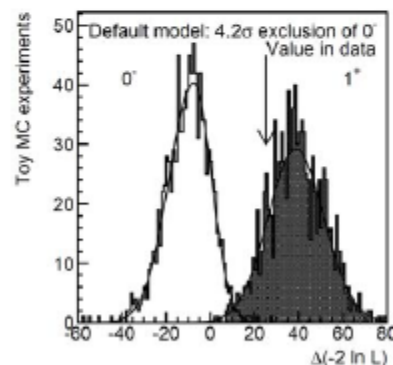
$$B(\bar{B}^0 \rightarrow \psi' K^- \pi^+) = (5.50 \pm 0.15 \pm 0.42) \times 10^{-4},$$

$$B(\bar{B}^0 \rightarrow \psi' K^*(892)) = (4.93^{+0.30+1.40}_{-0.23-0.43}) \times 10^{-4},$$



..... Fit result without Z^+

— Fit result with $Z^+ (J^P=1^+)$



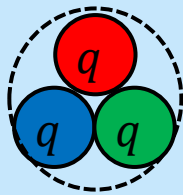
$$B(\bar{B}^0 \rightarrow Z(4430)^+ K^-) \times B(Z(4430)^+ \rightarrow \psi' \pi^+) =$$

$$(3.4^{+1.1+0.4}_{-0.7-1.3}) \times 10^{-5} \quad \text{for } J^P = 1^+ \text{ or}$$

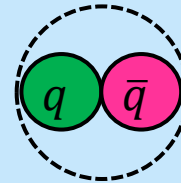
$$(1.4^{+0.8+0.6}_{-0.7-0.2}) \times 10^{-5} \quad \text{for } J^P = 0^-.$$

What is exotic

- Quarks do not appear as a single particle at **QCD**.

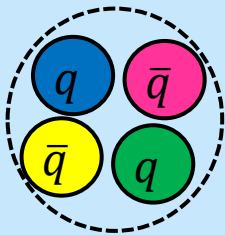


Baryons are
red-blue-
green triplets

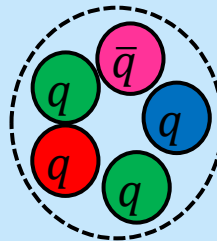


Mesons are
color-anticolor
pairs

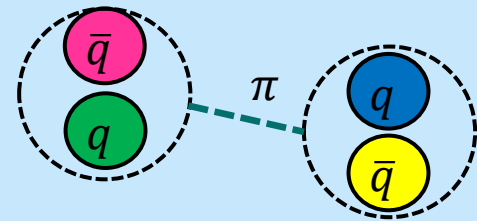
- Other possible components



Tetraquark:
Tightly bound diquark
and anti-diquark



Pentaquark:
Five quarks baryon
model

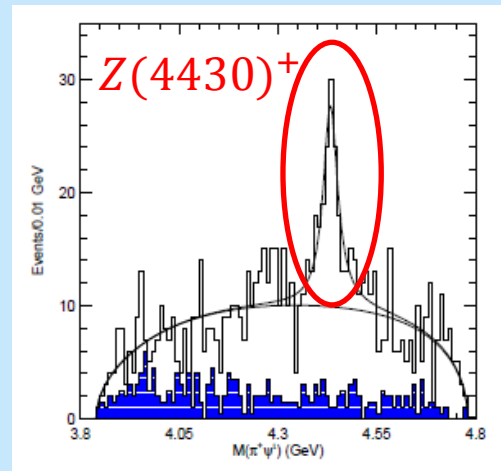
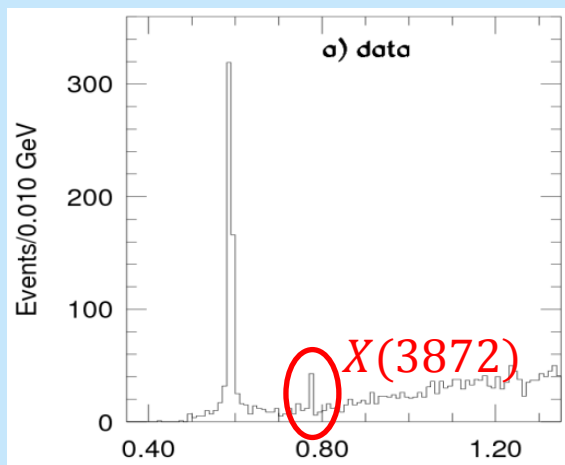


Molecule:
Loosely bound
meson-antimeson

X(3872) and Z(4430)⁺

■ Observed exotic particles at Belle

X(3872), Z(4430)⁺, Z_b(10610), Z_b(10650) etc.



■ Basic strategy to find exotic states

- To search the meson decaying into cc or similar state
- If observed particle's properties can't be explained easily...

most probably exotic state